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ABSTRACT

The level of thinking that is characteristic of the typical college freshman and the skills needed by college science courses are addressed, and the Development of Reasoning in Science project (Project DORIS) at California State University, Fullerton, is described. While the typical college freshman functions at the concrete level of thinking, many college science professors assume that students are capable of functioning at the formal operational level. Project DORIS, a course in abstract thinking for college science majors, focuses on the following thinking skills: combinatorial logic, correlation, hypothetical-deductive reasoning, isolation and control of variables, and proportional reasoning. First-year offerings in the sciences present concepts that can be taught with both concrete and formal thought processes. The teaching strategy incorporates exploration, invention, and discovery activities and enables the learner to use logic based on experience. As the student develops the reasoning skills associated with concrete thinking processes, the sequencing moves to a higher level with the objective of enhancing intellectual growth. Sample learning experiences from the various science content areas are described, along with the evaluation design for the project. (SW)

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Intellectual Development of College Science Students

Francis P. Collea

Problem Identification

Many college and university science departments make inadequate evaluations of students' ability to think logically. It appears that most science college courses have not taken into account the work of Jean Piaget and others concerned with intellectual development. Recent studies have shown that only a few beginning college students use all the strategies of formal thought confidently and reliably. A typical college freshman functions at the level of concrete experiences. He comes to college with inadequate skills to argue logically about the importance of a given principle when the context in which it is used is slightly altered. Many times he is unable to think logically about the simplest kind of problem.

Investigations have been conducted with college students to determine their level of thinking. McKinnon (1971), using Piagetian tasks, tested college freshmen at a large southwestern university. He found that 50 percent of these students were operating completely at Piaget's stage of concrete thinking. Another 25 percent were in transition from concrete to formal thought. Griffiths (1973) reported that his freshmen subjects, many of whom were physics and chemistry majors, were unable to use formal operational processes in solving problems. Tomlinson-Keasey (1972) reported that less than 50 percent of her female college students were able to exhibit formal thought on Piagetian tasks administered to them. In fact, Langer and Kuhn (1971) have estimated that many adults have not yet reached this level of formal thought.

If one closely examines the level of instruction of most college science courses, some interesting information is found. For example, many concepts and principles in the various scientific disciplines are developed through formal thinking processes. It appears that the thinking level of many college students doesn't coincide with the level of presentation of concepts by the college science instructor. Many professors make the assumption that their students can use abstract thinking skills in dealing with the course content. Most science and mathematics instructors assume their students are able to function at the formal operational level. From the data of the recent studies cited, it appears that many science students who are not operating at the formal thinking stage have great difficulty with these courses. They are not intellectually ready to think about abstractions! High rate of course failures, increased college dropouts, and unpopularity of these abstract courses are fairly commonplace in most institutions of higher learning, especially in the sciences. The cry of many college science teachers that students can't think could be attributed to this intellectual dichotomy: course content presentation at one level of intellectual thinking and students' thinking ability at another level.

The questions that arise as a result are quite provocative. What kinds of courses and programs in science are likely to enhance intellectual development in college students? How can science instructors at the college level develop teaching strategies that ease the transition from concrete thinking to formal thinking? How many experiences are necessary? How long will it take? Can we measure this intellectual growth? How do you make college professors aware of the intellectual growth patterns of their students? Can a science curriculum be reorganized around specific thinking skills rather than scientific content? Will as much cognition take place? Could the function of general education in science be designed to systematically teach the non-science major abstract thinking skills?

Spurred by these questions, California State University at Fullerton developed a course in abstract thinking for college science majors. Project DORIS (Development of Reasoning in Science) was developed in about a year, and in the past three semesters has shown significant advances in the development of students' thinking skills.

Experts in chemistry, earth science, mathematics, and physics designed the course which focuses on the following thinking skills: *1.* combinatorial logic, *2.* correlation, *3.* hypothetical-deductive reasoning, *4.* isolation and control of variables, and *5.* proportional reasoning. They selected concepts from the first-year course offerings in their respective departments, with the basic requirement that they select only those concepts that can be taught with both concrete and formal thought processes.

DORIS was built around a teaching strategy made up of three stages: exploration, invention, and discovery. Every lesson in the course begins with a set of exploration activities designed to provide a mismatch between the students' reasoning level and the level of reasoning required by the lesson, leading to what Piaget calls "disequilibrium." As the students' reasoning abilities are challenged, this disequilibrium increases their motivation and curiosity.

Invention, the next phase of the course, develops a skill or concept for the students. This provides an anchor for the experiences students acquire during exploration. Discovery, the last phase, requires the students to rearrange what they learned during exploration and invention in new and different ways. Using thinking skills in this manner is called self-regulation, and is the key to intellectual growth in the course.

The Process

Since the development of reasoning skills is the main objective of DORIS, the learning situation for each concept must be developed in a concrete manner. That is, the learner must be able to use logic based on experience. As he or she develops the reasoning skills associated with concrete thinking processes, the sequencing moves to a higher level. That is, the learner can be recycled through these same concepts again. This time the reasoning skills required to solve the problem are much more sophisticated. For example, the learner may have to relate and make inferences from observation and relate his or her viewpoint to that of others in a problem-solving situation. By spiralling back on each concept and using more difficult reasoning skills each time, intellectual growth can be enhanced.

Sample learning experiences from the various science content areas are described below: in physics, students begin with a simple system such as a cart moving down an inclined plane or a metal rod placed in a flame. From these experiments, the students have direct experiences in observing and recording exactly what happens. Next they isolate the relevant variables. They set up space-time relationships. The students are assisted in formulating more abstract models such as energy and pressure. Later more complex systems with several irrelevant variables are studied. Finally, systems in which not all the important variables are directly observable are examined.

In mathematics, systems can again be explored by manipulation and observation. For example, the student predicts the path of an ideal billiard ball shot from the corner of a billiard table at a 45 degree angle. This observation phase can be symbolic in the sense that graph paper rather than physical billiard tables can be used. These activities lead to the determination and separation of variables (variables such as table size and initial position velocity). From these data, the student can construct and verify hypotheses they have established. As a result of working with the variables, the concept of the ratio and parity of numbers will take on a concrete meaning. By a firm and concrete understanding of these concepts, an algorithm to determine where the ball ends up will be made, tested, and applied. By devising such concrete experiences for students as described above, many abstract concepts from college algebra and elementary calculus can be initially approached and easily understood in this manner.

Evaluation

Two project staff members have developed the evaluation design of the project. There will be two specific areas of investigation: cognition attainment and thinking processes development. Cognition is an important factor in this project. Learners must feel they are learning something while developing their thinking skills. One of the charges made by those who defend the disciplinary bases for learning in institutions of higher education is that content is sacrificed when emphasis is placed on developing thinking skills. Although little data exists to support this contention, it seems appropriate to test knowledge of content as well as development of thought processes in this project. Hence, science content knowledge will be tested periodically during the teaching phase of the project. Examinations, departmental tests and standardized testing material will be some of the devices used to measure content gain.

The second part of the evaluation design is to measure intellectual growth. Several investigators have developed tasks which measure concrete and formal thinking skills. Researchers such as Karplus (1974), Tomlinson-Keasey (1973) and Renner (1973) have designed a series of Piagetian tasks that measure intellectual development. Such tasks as proportional reasoning, combination logic, and deductive thinking will be among the thinking skills that will be closely monitored and tested. This project will use tests from all these researchers to measure intellectual growth. In addition, certain demographic data will be obtained from students who participate in the teaching phase of this project. Such factors as place of residence, age, honors, and college activities are a few examples of the kind of data that will be collected. This information might be useful to staff when looking at other factors that might affect intellectual growth.

Dissemination and Redesign

California State University, Fullerton is deeply concerned about students who have difficulty making the transition from high school to college, especially in the sciences. The Science Learning

Resources Laboratory is an attempt by the School of Mathematics, Science and Engineering to provide small and personalized learning situations for students enrolled in science courses. If this project can enhance intellectual development in college freshmen, then the Resources Laboratory will have played an important role in this successful venture.

Finally, the project will publish a monthly newsletter concerning its progress during the project. This newsletter will be made available to any science faculty, department, or institution of higher learning that is sincerely concerned with the intellectual development of students.

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